BIOGRAPHICAL MEMOIRS

David Colin Sherrington. 5 March 1945 — 4 October 2014

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Elected FRS 2007

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David Colin Sherrington began life as a Liverpool docker’s son and became an internationally recognized authority on reactive polymers and using polymer-supported reagents in novel applications. His research career began at University of Liverpool with his PhD work on the mechanisms of cationic polymerization. From 1972 until retirement in 2010, Strathclyde University was his chief research base. In the very early years he continued with mechanistic and kinetic studies of cationic polymerization, but soon moved to the field of polymer-supported reactions and reagents, to which he devoted the rest of his research career. An important contribution to the direction of his scientific activity was the secondment years he spent at Unilever, where he became involved in polymeric high internal phase emulsions (polyHIPEs). In the following years, he devoted much effort to accurate characterization of these and other porous polymer supports, frequently involving him in learning new techniques (e.g. neutron scattering). An important feature was the use of polymer supports to catalyse oxidation reactions, especially olefin epoxidation. He gained valuable insight into many aspects of his research from the many visiting professorships over his career. He was involved on the editorial board of Reactive Polymers continuously from 1982 until 2010 and he was awarded many honours. His free time was mainly devoted to fishing, particularly for salmon, an activity he shared with his wife and a group of friends for many years. His warmth, intellect and clear interest in the careers of his research students were key components in creating the

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polymer ‘family’ to which they belonged. His years of retirement were saddened by multiple system atrophy, a devastating illness throughout which he was cared for by Val, his wife.

PARENTAGE, YOUTH AND UNIVERSITY OF LIVERPOOL

David Colin Sherrington was born on 5 March 1945, the second child of Alfred George Sherrington and Lucy Gladys Sherrington, née Pyke. His father was a dock labourer in Liverpool docks (8am to 7pm, six days a week and often on Sundays too) and his mother a school cleaner and dinner lady. At the time, dock labour was casual and overseers selected men from the ‘pen’ on a daily basis for work; consequently, employment was unpredictable and the certainty of income precarious. The family—there were also two sisters Norma (born 1941) and Lynda (born 1946)—all lived in a two-up, two-down house in Webster Street, Litherland, Liverpool 21. In 1947 the family was rehoused in a new housing development in nearby Osborne Road.

David attended two primary/junior schools: Lander Road Primary and Beech Road School, being moved from the former because bomb damage from the Second World War restricted available space. Apparently, when the family moved to Osborne Road there were gangs of boys who had frequent ‘run ins’ with the local police. However, David was seen as a quiet, reserved lad who had no involvement with any of the gangs. His time was spent train spotting at Aintree station, following Liverpool Football Club’s fortunes and pursuing his lifelong passion of fishing. This was developed by joining his father fishing on the Liverpool–Leeds canal and then in the Strand Angling Club in nearby Bootle. When he acquired a driving licence and a Mini car he made fishing trips to North Wales, where any trout he caught were sold to hotels on the way back home. His father also influenced David in another way: Alf encouraged all his children to pursue their education to the full.

David passed his 11-plus exam to Waterloo Grammar School, where he had an early serious interest and liking for Latin, but was not outstanding in lower school chemistry. School reports exhorted him to participate more in house activities, but to little effect. However, by the time he was in the Sixth Form, he was clearly far better than the average pupil, since his A level results were sufficient for him to by-pass the first (introductory) year of the then four-year chemistry degree course at University of Liverpool and enter the second year in 1963. He was also awarded a Sir W. H. Tate Science Scholarship by the university. Only one scholarship was available each year and the winner held it for three years. Candidates had to sit three A level exam papers from those listed plus additional Special level papers in two of these. Success resulted in £40.00 per year! Not a great deal of money now, but in 1963 the UK average annual wage was £650 and, doubtless, that of a dock worker was far less.

At the time, the chemistry course at Liverpool seems to have been somewhat anchored in the past since the final year honours school was divided into specializations in organic or physical chemistry, with undergraduates having to choose one or the other, and all had a common course in inorganic and general chemistry. (If this seems somewhat quaint, it is perhaps salutary to note that when James Chadwick (1891–1974, FRS 1927), the Nobel Prize winner, joined the physics department at University of Liverpool in 1937 it only had DC power—no basis for a modern physics course!) Surprisingly, in view of his later career, David chose the physical chemistry option. The choice may have been due to two people who were...
both influential in different ways on David’s future career: Tony Ledwith (1933–2015; FRS 1995) and Alastair M. North. His final year undergraduate research project was supervised by Tony Ledwith and was an investigation of the kinetics of cationic polymerization of isobutyl vinyl ether. Reading the resultant thesis in the knowledge of the technology advances made since 1966, one may conclude that the project was not very challenging. However, in 1966 a project involving high vacuum and low(ish) temperature calorimetry, with none of the computer-assisted data recording and control now available, must have been very demanding. Vacuum line procedures might have been well developed and practised in Ledwith’s research laboratory, but they will most likely have been quite unknown to an undergraduate in 1966. David graduated with a first-class degree in 1966, but was disappointed in coming second in the class list rather than at the top, for which he had worked and on which he had set his sights. Following graduation, he embarked on a PhD by research at Liverpool under the supervision of Tony Ledwith working on the reactivity of free ions in vinyl polymerization. An early illustration of David’s ebullient personality was his willingness to respond to sing requests from academic staff when in the research lab (he had a good singing voice and a large repertoire of Tom Jones songs).

While he was working on his PhD, Alf was badly injured in a dockyard accident when a hold hatch cover fell on him. David was with his father when he died a week later in hospital. One of the consequences of this tragedy was that David took his father’s place in escorting his elder sister, Norma, down the aisle at her wedding in 1969. After completing his PhD, his original intention before his father’s death was to undertake post-doctoral research in Canada, since he was intent on an academic career. However, he stayed on at Liverpool in Ledwith’s group as a research assistant to help his recently widowed mother. Ledwith had many contacts abroad which, if asked, he would have deployed to help David in his career.

For those of us who knew David in later life it is surprising to learn that in his youth, and for much of his University of Liverpool career, David was overweight, to the extent that his doctor advised him to lose weight or severe problems might ensue. The problem apparently was due to an abiding love for food! One must also bear in mind that fishing, although restful and calming, is sedentary. He took up squash, rapidly lost weight and played the game on a daily basis for many years thereafter. It was through squash that he met Valerie Vinnicombe, his future wife. Val was a secretary in Senate House at the university and a member of the squash club. David decided to ask her to the end-of-year chemistry department cheese and wine party, but that evening she was not at the squash club. So, he went round to the house where Val lived with her mother and knocked on the door; her mother asked him in. Val apparently was not best pleased as she had no excuse ready; however, one thing led to another and seven weeks later they were engaged to be married!

At some point, we all have to fly the academic nest and David applied for two lectureships in 1971: one at Heriot-Watt University and one at Strathclyde. Here is where chance and circumstance cross: another applicant for the Heriot-Watt post was Ian Soutar (1945–2003, subsequently professor of chemistry at University of Sheffield), who was the successful applicant. David took the interview at University of Strathclyde, which was for a post in the physical chemistry section of the department of pure and applied chemistry headed by Alastair M. North, who had supervised Soutar in his PhD! David was successful in obtaining the post and he and Val were married in 1972 after he promised his future mother-in-law that they would only be away for three years. However, apart from sabbatical interludes and a period at Unilever, he never left Strathclyde.
Initially, at Strathclyde David continued in research on cationic polymerization, but by 1975 the focus of his research had shifted to polymer-supported phase transfer catalysis and polymer-supported reactions. This shift may have been the beginnings of David’s realization that he was more of a synthetic organic chemist than a physical chemist. This was in the sense that he wanted something useful and useable to come from his research rather than a deep understanding of the kinetics of polymerization, which had been very much the thrall of polymer chemistry research since the 1930s due to the fascination with chain reactions. To some extent this desire to obtain something useful may have been latent since his time at Liverpool, which, in 1961, had received a strong industrial impetus by the arrival of Clement Bamford (1912–1999, FRS 1964), always known as ‘Bam’, together with colleagues from the Courtaulds long term research laboratory at Maidenhead. In time, Bam had been succeeded as professor of industrial chemistry by Tony Ledwith.

Consequently, with this increasing desire to provide useful materials and an awareness of industrial chemistry, it was unsurprising that in 1984 David accepted a three-year contract to work at Unilever’s Port Sunlight laboratory. This was due to the, then, research director of Unilever, Sir Geoffrey Allen (FRS 1976), who was re-invigorating the input of basic research to Unilever’s business. Port Sunlight sought someone with the following profile (in current recruitment speak):

- A very good scientist with an original mind
- An ability to appreciate the application of science in different areas
- Able to bridge generational gaps and the divide between researchers and administrators
- A quick appreciation of possible applications and an ability to explain them to non-scientists (aka ‘suits’).

David fulfilled these requirements and had three very successful years at Unilever, where he was much appreciated as someone who could give ‘front line’ advice. David was recruited to build and lead the Polymer Science Area. Before his arrival most of the polymer development work consisted of collaborations with chemical suppliers, i.e. they provided a specific polymer and Unilever did its best to formulate and evaluate for a particular application. A major role was the provision of strategies for the development of functional polymers for home and personal care applications with business leaders, marketing, consumer scientists and formulators. Inter alia with these aspects was the recruitment and training of polymer scientists. The areas David worked on at Unilever, and which had impact on its business, included: microencapsulation (in recent years this technology has been successfully commercialized globally in laundry detergents); biodegradable polymers; rheology modifiers; deposition aid polymers for 2-in-1 shampoo; stabilization of colourants in bleach products; and molecular imprinting.

One area that he developed whilst at Unilever was PolyHIPEs (Feuerabendt et al. 2014)—crosslinked high internal phase polymers—which were subsequently much used as
supports for reagents. Originally, polyHIPEs were based on polyvinyls made by radical polymerization reactions; under David’s leadership, this was expanded to polycondensation polyHIPEs. The potential application areas of these materials explored by David included: solid phase synthesis of peptides; solid phase synthesis of oligoethers; soft surface cleaning wipes and window wipes; perfume supports in air fresheners; alumina polyHIPEs in exhaust emission catalysts; polymeric surface active agents; and colloid stabilizers.

The key application of polyHIPEs which David initiated at Port Sunlight was solid phase peptide synthesis; he successfully made several bioactive peptides that were explored for a variety of applications in the personal care area. As a result, Unilever initiated a programme with National Starch (part of Unilever at the time) to commercialize polyHIPE supports. This was a huge activity and finally Unilever licensed this technology to Bio-Rad.

There were in excess of 22 patents awarded in the polyHIPEs area; some of these were still being applied for and granted in the early 2000s, some 20 years after David went to Unilever, a testament to the universality of their application. Also, there were some 15 patents in laundry products: rinse aids, perfume deposition, etc. This was a very productive time for David, and collaboration with colleagues at Unilever, e.g. Ezat Khoshdel, continued to the end of his working life.

**STRATHCLYDE YEARS 2**

David returned to Strathclyde in 1987 as a full professor and eventually head of the organic chemistry section. In the succeeding years, he developed a large and international research group. One of his PhD students, Sid Simpson, who had been junior accordion champion of Scotland, composed the ‘Sherrington’s Reel’ for David—I am told it is difficult and requires great expertise on an accordion (figure 1). A feature of his career at Strathclyde was the time he devoted to preparing and giving talks to audiences of young people, not only in Strathclyde, but also in St Andrews and at Keele University, for example. The main objective was to enthuse people by demonstrating that chemistry could be fun, and the emphasis was on the demonstrating. At least one young man changed his career choice as a result of attending one these talks, swapping to chemistry, which he pursued successfully at Oxford University.

David’s reputation was such that he held visiting chairs at the University of Pisa; University of Tanta, Egypt; University of Nankai, China; University of Bombay; University of Oulu, Finland; University of Bordeaux; University of Gyeongsang, South Korea; and the Tokyo Institute of Technology. He was elected Fellow of the Royal Society of Chemistry in 1981 and of the Royal Society of Edinburgh in 1990, and awarded the Beilby Medal and J. B. Goodenough Award from the Royal Society of Chemistry in 1993 and 2009, respectively, together with the MacroGroup medal in 2002. His professional approach and knowledge of polymer science, especially the synthetic aspects, were of great value during his membership of the Council of the High Polymer Research Group (HPRG, www.highpolymer.org.uk), which held annual meetings at the Manor House Hotel at Moretonhampstead, Dartmoor. During his long membership of the council, David organized several programmes and was perhaps the longest-standing member when the venue for the meetings had to change to Pott Shrigley in 2003.

Throughout his career, David was on the editorial boards of several journals including *Reactive Polymers*, *Polymers for Advanced Technologies* and *Chemical Communications*. In addition to his more than 20-year interaction with Unilever, David’s expertise was called on by
During this time David maintained his passion for fishing, which, until he arrived at Strathclyde, had been mainly ‘coarse’ fishing, i.e. catching residential fish in lakes, rivers and canals using live bait. Through a colleague at Strathclyde (Graham Knox) David was introduced to game fishing: catching sea trout and salmon using artificial flies—he was hooked! For many years, David and Val were part of a group of between 10 and 16 people who each year rented a house in Lochcarron in Wester Ross at Easter, summer and September; apparently, the wives were good cooks and the men efficient at gutting fish and popping corks. David rapidly became an expert in game fishing and challenged, and often beat, friends who had pursued the sport for much longer. The passion for fishing among this group of friends was such that wives took up fishing also and gave the men a good run for their money. Even on walks on the hills and Munros nearby, trout rods were carried just in case a hill loch of interest was encountered.

David’s wife, Val, had been warned by her mother that she would not defeat the passion for fishing—so best join in. She joined in to such an extent that on their Silver Wedding trip to Alaska in 1997 she caught a 62 lb Chinook salmon on the Kenai River; not to be outdone, on the same day David caught a 78 lb fish, the largest caught on the river up to that time. This fish has a place in academic records. David was asked by Jim Feast (FRS 1996) to act as an external examiner for one of his PhD students at Durham University. The university required evidence of recent achievement(s) to establish the bona fides of the examiner. Instead of a
list of papers published, prizes won, lectures given and so on, David, at his mischievous best, provided a photograph of himself with this huge fish, which Jim submitted to the university authorities (figure 2). It was accepted as sufficient evidence of his standing.

In addition to fishing, for many years David and Val would go skiing with friends, Ian and Janet Dunkin. Although David did not ski, he went walking in the woods and hills nearby and saw much more of the wildlife than the skiers. He took this seriously enough to buy snow shoes to enable more efficient walking. Frequently, these trips coincided with St Valentine’s Day and David would get up early on the day and trace a huge heart in the snow underneath their bedroom window.

David was always a sociable, warm person who endeavoured to get along with all; this was especially so where children were concerned. Although he had no children of his own, David was always able to interact with children in a way such that they knew they were not being patronized and appreciated being respected. Of course, it helped that David had a mischievous sense of humour and was very much the prankster which all children appreciate. This was particularly evident in Wester Ross, where he joined in with children building dams and playing jokes on the ‘grown ups’. Each Guy Fawkes Night, David and Val would have a
bonfire party for friends and their children and David’s overseas students; a huge bonfire, an arsenal of fireworks, hot soup, food, parkin and a lethal mulled wine meant that all enjoyed themselves, and the neighbours sat on the wall and enjoyed the firework display. David’s mischievousness has been referred to earlier; quite often this mischief was not for public consumption, but kept between those involved. R.W.R. notes it was not until his own two sons reached adulthood that they told him that when they were 6 and 8 years old, respectively, David took them for a ride in his new car. ‘Can it do 100 mph?’ from small voices. ‘Yes’ was the reply and then he promptly proved it! Afterwards the boys were sworn to secrecy and not to tell mum and dad, and they never did, such was the regard and affection they had for David, and these were also the feelings of all who knew him as a friend and colleague.

This warmth of personality was also apparent in his professional life, and the creation of a team ethic and identity of his research group. The word ‘family’ has been used by his students to describe the nature of the group, which was a very heterogeneous collection of people, kept together by David’s integrity and devotion to ensuring that the research students contributed to the best of their ability (figure 3). He maintained a paternal interest in their development and careers after they had left the group. An annual feature was the weekend away for the whole group organized by a small number of people who arranged accommodation and ensured that the food represented all the nationalities of people in the group; this was lubricated by wine provided by David and his wife (figure 4). Some of the events and happenings were quite hair raising; on one such weekend, one of the party had to be helicoptered off the Cairngorms after breaking his ankle at 2500 feet up.

For a number of years David was troubled by a pain in his lower back, which came and went but was never identified. When present this pain curtailed his ability to do anything physical like hill walking, which he greatly enjoyed, and the pain meant that he could not adopt the same position, whether sitting or standing, for very long. It was shortly before his retirement that he became aware that something more serious was amiss since he began having difficulty maintaining stability whilst walking. Parkinson’s disease was the initial diagnosis,
but the final diagnosis of multiple system atrophy (MSA) was much more devastating. MSA is a neurological disorder associated with degeneration of nerve cells in the brain, the incidence is around 4 people per 100,000 worldwide, there is no known cure and diagnosis is difficult due to its rarity and the variety of symptoms by which it manifests itself. Unlike Parkinson’s disease, MSA does not respond to dopamine treatment. The degeneration of the nerve cells results in gradual loss of autonomic functions of the body including slowness and stiffness of movement (and eventually total inability to walk), difficulty with balance and vocal cord paralysis, among other symptoms. However, the brain remains active and aware of the degradation. David faced his gradual decay with courage, fortitude and strength and rarely spoke despairingly of his condition. He gained tremendous support in his decline from the care and attention of Val, who devoted 24 hours a day to him. Even quite near the end of his life he was able to enjoy, to some extent, the Friday evenings when friends came around with Chinese or Indian food and he could have a glass of wine and be part of the conversation, even if not able to participate fully. In the summer of 2014, David had a severe attack of aspiration pneumonia and was hospitalized for several weeks, much to his dislike—he wanted to be at home. Pneumonia recurred again in October of 2014, by which time his resistance was weakened to the extent that he died in the early hours of 4 October 2014 at the age of 69.

**SCIENTIFIC WORK**

In his early years at the University of Strathclyde David continued to work on cationic polymerization, often in collaboration with his former PhD supervisor, Tony Ledwith.
However, it is very likely that during this time David was looking for a new area of research, one where he could make his own mark.

To trace the background to what ultimately proved to be one of his major areas of research, we need to go back to the 1930s and 1940s and the development of ion exchange resins. Ion exchange was originally carried out using natural minerals such as zeolites, but subsequently synthetic materials were developed, mainly as a result of research in industrial laboratories. A major step forward came in 1935, when Adams and Holmes described the preparation of some phenol-formaldehyde particles and their use for ion exchange (Adams & Holmes 1935). Then, in the late 1940s and 1950s, these were displaced by poly(styrene-divinylbenzene)-based ion exchange resins. These polymeric materials have the advantage that they can be chemically modified easily to give a wide variety of ion exchange types. For example, sulfonic acid (for cation exchange) or quaternary ammonium groups (for anion exchange) can be introduced easily. The next development, and one that drew further attention to poly(styrene-divinylbenzene)-based resins, was the work of Hohenstein and Mark, who described in detail a suspension polymerization of styrene and divinylbenzene which produced, on either a laboratory scale or an industrial scale, high quality spherical beads of an appropriate size for ion exchange work (Hohenstein & Mark 1946). Moreover, the beads had reasonably narrow size distributions; such beads pack well in columns and afford good flow characteristics. From the 1950s onwards, a range of cation exchange resins, containing sulfonic or carboxylic acid groups, and a range of anion exchange resins, containing quaternary ammonium or amine groups, became available from several companies.

These ion exchange materials were also used for other purposes. For example, the sulfonic acid resins were used as strong acid catalysts for ketal formation or hydrolysis, carboxylate ester formation or hydrolysis, dehydration and many other reactions. These were very early examples of polymer-supported catalysts. In 1962, a book by Fred Helferrich entitled *Ion exchange* was published that for many years was the reference point for this area (Helferrich 1962).

In 1963 Bruce Merrifield reported a major development in a very different scientific field from ion exchange (Merrifield 1963). Merrifield’s team at the Rockefeller Institute in New York worked on the very important subject of peptide synthesis. Their new approach used crosslinked polystyrene beads and became known as ‘solid phase peptide synthesis’ (SPPS). In their SPPS, the first amino acid of the target peptide, in an N-protected form, is chemically linked to chloromethylated polystyrene beads via the carboxylic acid group. The N-protecting group is then removed and the second protected amino acid attached. In the initial report, this cycle of reactions was repeated until a tetrapeptide had been produced (Merrifield 1963). The principal advantages of this synthetic approach are that, after each reaction, the growing peptide chain is easily recovered and freed from excess reagents and soluble by-products simply by filtration and washing. Indeed, the whole process is easily automated and in 1966 Merrifield, Stewart and Jernberg described an automatic synthesizer that they used to synthesize several nonapeptides (Merrifield et al. 1966). SPPS in flow systems followed. The advantages of using an insoluble polymer support in organic reactions, as exemplified above, generally apply to the many other types of polymer-supported reactions, discussed later. The invention of SPPS earned Merrifield the 1984 Nobel Prize for Chemistry.

It is often overlooked that, at almost the same time as Merrifield’s advance, Bob Letsinger, at Northwestern University, also developed an SPPS. In his approach, the first amino acid is linked to the insoluble support via the amine group rather than the carboxylic acid group. This
was first reported in 1963 (Letsinger & Kornet 1963). A problem with this approach proved to be that some racemization of the bound amino acid residues occurs. Letsinger soon developed his approach to give a ‘solid phase nucleotide synthesis’ and this has proved to be very useful (Letsinger & Mahadevan 1965).

In the years following the reports of SPPS, mainstream organic chemists began to investigate the application of Merrifield’s general ideas to other areas of organic chemistry. This led to the widespread study of organic reactions using polymer-supported substrates, protecting groups, reagents or catalysts. Progress was slow at first, but by the early 1970s several examples of each type of reaction had been reported in the literature. Since then supported organic reactions have been of great interest in connection with combinatorial chemistry, high throughput synthesis and green chemistry. All of this work using supported reactions stimulated great interest in the preparation and characterization of insoluble supports. What is the best support for a particular application, why is it the best and how can it be prepared reproducibly?

It was at this stage, in 1973–74, that David Sherrington entered the field. His particular and long-lasting interest, that developed considerably over his career, was the synthesis and characterization of a wide variety of insoluble supports. Most were prepared by suspension polymerization. Generally with beads of sizes that allow easy filtration, few reactive groups are actually on the bead surface: the vast majority are within the beads. For the reactants in solution to be able to access the groups within the beads, it is necessary for the reactants in solution to be able to diffuse into the beads. One way of achieving this is by the use of lightly crosslinked gels (gel type or microporous beads) that swell greatly in the reaction solvent, so opening up channels in the beads. This approach works well in many cases, but it can have its problems and limitations. For example, the swollen beads are physically soft and if they are used in columns they tend to compress, causing column blocks. This raises interest in alternative approaches. A very important one, and one that David Sherrington spent a lot of time studying, is to prepare solid supports that possess and retain a highly porous structure even in the absence of a solvent (macroporous or macroreticular beads). The porous structure is generally maintained by the use of high levels of crosslinking: this confers a rigidity to the support. It also means such beads have two major features of interest: a highly crosslinked ‘skeleton’ and large pores. Macroporous beads, like gel type beads, can also be prepared by suspension polymerization, but there is now the added complication of developing the porous structure. The latter is usually achieved by using a porogen (defined as a mass of particles, of a specified shape and size, used to make pores in moulded structures that are dissolved away after the structure has set). In later years, David adapted for suspension polymerization an invention of Malcolm Mackley, who was based in chemical engineering at the University of Cambridge, that involves a baffled oscillatory reactor. David’s adaptation (11)* allows suspension polymerizations to be carried out reproducibly on a small scale (e.g. 1 gram).

Suspension polymerization can be an extremely complex process because the nature of the product is very sensitive to the experimental conditions. For example, the average bead size and the range of sizes obtained depend, among other things, on the actual monomer(s), on the shape and size of the reactor vessel, the shape and size of the stirrer, the stirring speed, the nature and amount of surfactant used, and the nature and amount of any porogens. Different chemical functionalities are needed for different applications, and Sherrington developed
excellent procedures to give the desired results for the suspension polymerization of not only styrene-based beads, but also beads prepared from a wide variety of other starting monomers, such as methyl methacrylate, glycidyl methacrylate, N,N-dimethylacrylamide, acrylonitrile, vinyl pyridine and vinyl imidazole.

In addition to the standard microporous and macroporous supports, Sherrington also prepared several types of more complex insoluble supports. Notable among these were polymers prepared using polyHIPEs, that could be prepared in powder, column, film or disk formats (7). Other types are composites where a physically soft polymer is prepared inside the pores of a physically strong inert inorganic solid, such as kieselguhr, and a very high surface area bead prepared by the self-assembly of monodisperse polymer nanospheres. One interesting support was a soft polyacrylamide prepared inside a polyHIPE. This was useful for a continuous-flow SPPS (5). Sherrington used most of the types of support noted above to, for example, prepare ion exchange materials and/or to prepare polymer-supported catalysts.

Because of their insolubility, solid supports are not easy to characterize. Sherrington used and developed a wide variety of techniques to characterize and understand the structure and performance of the various supports his research group prepared. For example, optical microscopy, electron microscopy, swelling and de-swelling experiments, $^{13}$C nuclear magnetic resonance spectroscopy on both swollen beads and in the solid state, transmission electron microscopy, small angle neutron scattering, and mercury porosimetry. Although most of these techniques had been used before in other contexts, they had not been used to characterize the insoluble supports prepared for use in organic synthesis.

Sherrington’s first published paper on polymer-supported species appeared in 1976. The study involved the synthesis of a range of crosslinked polystyrene beads, including both microporous and macroporous types, containing triphenylphosphine residues and their reactions with alcohols in carbon tetrachloride solution to give alkyl chlorides (1). The performance of the different beads was correlated with their different physical structures. It should be noted that beads with phosphine residues are widely used, for example, to support transition metal complex catalysts.

Reference has been made earlier to the HPRG. This was initiated by some of the academic polymer scientists of the late 1950s, namely, Sir Harry Melville (1908–2000; FRS 1937), Cecil Bawn (1908–2003; FRS 1952), John Bevington (1922–2007) and Fred Dainton (Baron Dainton of Hallam Moors, 1914–1997; FRS 1957), with generous financial support from industry. The objective of the HPRG was (and continues to be) the organization of an annual conference on topical areas in polymer science and engineering. Attendance is by invitation only and until 2003 the conferences were held at a hotel in Moretonhampstead in Devon. Since 2003 they have been held at Pott Shrigley in Cheshire. Both venues share a remoteness from the nearest town and thus discussion and conversation among participants are fostered. In 1977, at a meeting which included Reactive Polymers, one of the present authors (P.H.) and David Sherrington met for the first time. Over a steak and wine dinner they decided to try to edit a book on the rapidly growing area of reactive polymers. At the time, there were very few books on this topic and John Wiley at Chichester agreed to support the venture. A major aim was to draw together all the relevant organic chemistry and polymer science into one place. Several prominent researchers and both editors contributed chapters. The book appeared in 1980 and became a major reference book for the area for the next decade or so (2). A second book with the same editors appeared in 1988 (4).
In 1982, a conference organized by Dr George Gelbard was held in Lyon, France, on the topic of polymer-supported organic reactions. This was so successful that one of the present authors (P.H.) and David organized a second conference in 1984 in Lancaster, UK. Subsequently, every two years for the next 20–30 years, similar international conferences have been held around the world. David was either on the advisory committee, helped to organize the scientific programme and/or was a speaker at many of these meetings.

A type of reaction that attracted considerable interest in the 1970s and 1980s was phase transfer catalysed (PTC) reactions. Typically, these involve a reaction between an organic molecule, such as an alkyl halide, in an organic solvent, such as dichloromethane, and a base or salt, such as potassium acetate, in water. A catalyst is used to facilitate the transfer of the base or anion from the aqueous phase to the organic phase, where it reacts. Common catalysts are bulky organic-soluble quaternary ammonium salts or crown ethers. The technique avoids the use of solvents such as dimethyl sulfoxide and N,N-dimethylformamide, which are relatively expensive and can be difficult to remove efficiently after the reaction. PTC is also useful for carrying out reactions on functional groups, especially chloromethyl groups, on polystyrene beads with nucleophiles in water. David made notable studies using a wide range of amphiphilic polymers, both soluble and as insoluble beads, as phase transfer catalysts, and correlated the results with the polymer structures.

For one application David used crosslinked beads as the stationary phase in analytical chromatography. This required relatively small beads with a very large surface area. He prepared several supports which served well in this role. An important extension of this work was the preparation of supports imprinted with a specific molecule, a topic first studied by Klaus Mosbach in Sweden and by Gunter Wulff in Germany. These supports can then be used to analyse mixtures containing closely related molecules by a type of affinity chromatography. Similar materials could be used for solid phase extractions from water. Examples David prepared include ones to bind amoxicillin, cephalaxin, cephalosporin C, ciprofloxacin, carbamazepine, naproxen and naphthalene sulfonates. The polymers could also be used to concentrate the analyte in analytical procedures.

Another application that he frequently studied was to introduce sites onto polymer beads that would allow binding of a particular metal ion. Beads which would bind Cu^{2+}, Zn^{2+} or Hg^{2+} were often studied and, for example, beads which could bind the copper cations selectively in the presence of zinc cations were successfully developed (3). Many of these studies were carried out in collaboration with Professor Jan Reedijk’s group at Leiden in the Netherlands.

The next logical step forward in David’s research was to bind transition metal complexes to appropriate supports to afford polymer-supported catalysts. Often the reactions studied involved oxidation, so it was clearly advantageous to use the supports he had developed that were relatively stable to oxidation, for example, the benzimidazole-based supports. Often, many versions of a given catalyst were prepared and the performances were carefully studied and optimized. The first of these was a series of catalysts based on amine- or imidazole-bound Mo(VI) complexes (6). The best of these proved to be the catalyst based on polybenzimidazole. This catalysed the epoxidation of propene with tert-butyl hydroperoxide in very high yield and there was very little leaching of the metal. The supported catalyst recycled efficiently.

The oxidation of certain olefins produces an epoxide which is potentially chiral. An important reaction in this context is epoxidation catalysed by the Sharpless catalyst.
David prepared various heterogeneous versions of this catalyst by preparing a range of crosslinked poly(tartrate ester)s and reacting them with titanium tetraisopropoxide (8). Some of these products catalysed the epoxidation of allylic alcohols by tert-butyl hydroperoxide to give enantiomeric excesses comparable to those achieved using diethyl tartrate, though the actual value depended greatly on the polymer architecture and the ratio of metal to ligand. Another chiral epoxidation catalyst investigated was Jacobsen’s catalyst bound to polystyrene or polymethacrylate supports (9). This uses a chiral Mn(III) salen complex and m-chloroperoxybenzoic acid as the oxidant in combination with 4-methylmorpholine-N-oxide. In one case, the enantiomeric excess obtained (91–92%) was the same as that obtained with the soluble analogue, though the catalysts recycled poorly. Finally, a platinum-based catalyst bound to a high surface area polystyrene resin was developed for the efficient solventless hydroxylation of oct-1-ene using methyl dichlorosilane (10). Other metal species bound and used as polymer-supported catalysts include Pd(II), Zr(IV), V(V) and Pd(0).

From the 1990s onwards dendritic molecules and hyperbranched polymers became of considerable international interest. The synthesis of dendrimers is very time consuming, but hyperbranched polymers have many physical properties that are similar and they can be easier to prepare. Using his earlier experience of vinyl polymerization, David developed free radical polymerizations of methyl methacrylate (12), methacrylic acid and vinyl acetate that afforded hyperbranched polymers in one-pot syntheses. The key was to use, for example, methyl methacrylate together with a divinyl monomer such as ethylene glycol dimethacrylate together with appropriate levels of n-dodecanethiol to inhibit chain transfer and prevent gelation.

David began his career studying polymer synthesis and throughout he accomplished some novel syntheses. He believed that if a student had done a useful piece of work, as in the introduction in a thesis, it should be published. This prompted him to publish numerous papers and reviews, not only on those topics for which he was well known, but on other topics such as ‘Pumice as an aid in industrial chemistry’, ‘Agricultural polymers with combined herbicide/fertilizer function’, and ‘Bifurcated modular syntheses of chiral annulet triazacyclononanes’!

It is very evident that David Sherrington made a major and unique impact on polymer science by enthusiastically bringing the rigour of physical chemistry to a new and rapidly expanding area of the subject and by being keen to collaborate with experts in other disciplines.

**Career Summary**

1950–1956  Beach Road Boys Primary (Litherland, Liverpool)
1956–1963  Waterloo Boys Grammar School (Crosby, Liverpool)
1963–1966  Chemistry, University of Liverpool
1966  BSc first class honours
1966–1969  Research under supervision of Dr Tony Ledwith on reactivity of free ions in vinyl polymerization, University of Liverpool
1969  PhD, University of Liverpool
1969–1971  Research assistant, University of Liverpool
1971–1983  Lecturer, Department of Pure and Applied Chemistry, University of Strathclyde
1983–1987 Senior lecturer, University of Strathclyde
1984–1987 Research scientist, Unilever Research, Port Sunlight Laboratories
1986–1987 Polymer science area head, Unilever Research
1987 Reader, University of Strathclyde
1987–2010 Professor of polymer chemistry, University of Strathclyde
1992 DSc, University of Liverpool
1992–2005 Head of organic chemistry section, University of Strathclyde
1995–1998 Deputy head of department, University of Strathclyde
2010 Research professor, University of Strathclyde
2010 Professor emeritus, University of Strathclyde

**SERVICES TO THE SCIENTIFIC COMMUNITY**

Editorial advisory board, Royal Society of Chemistry, *Chemical Communications*

**SIGNIFICANT HONOURS AND AWARDS**

1963–1966 Sir W. H. Tate Scholarship, University of Liverpool
1981 Fellow of the Royal Society of Chemistry and Chartered Chemist
1981 Senior Ciba–Geigy Research Fellow, University of Pisa, Italy
1984 Visiting Professor, University of Tanta, Egypt
1990 Fellow of the Royal Society of Edinburgh
1992 DSc, University of Liverpool
1992 Visiting Professor, University of Nankai, People’s Republic of China
1993 Royal Society of Chemistry/Society of Chemical Industry Beilby Medallist
1994 Monbusho Visiting Professor, Tokyo Institute of Technology, Japan
1995 K. S. S. Raghvan Visiting Professor of Polymer Science and Technology and Professor B. D. Tilak Visiting Fellow, University of Bombay, India
1996 Visiting Professor, University of Oulu, Finland
1996 Visiting Professor, University of Gyeongsang, Chinju, Korea
1997 Visiting Professor, University of Bordeaux, France
1998 Visiting Professor, University of Gyeongsang, Chinju, Korea
2001 Visiting Professor, University of Bordeaux, France
2002 Royal Society of Chemistry/Society of Chemical Industry Macrogroup Silver Medallist
2006 Fellow of the Higher Education Academy
2007 Fellow of the Royal Society
2009 Royal Society of Chemistry J. B. Goodenough Award
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AUTHOR PROFILES

Randal W. Richards

Randal gained his PhD in polymer physical chemistry in 1971. After post-doctoral posts in Germany and Imperial College, he joined the Department of Pure and Applied Chemistry, University of Strathclyde, in 1977, where he met David Sherrington and became friend as well as colleague. He left Strathclyde in 1989 to join the Department of Chemistry, Durham University, where he stayed until 2003, when he was head of department. He joined the Engineering and Physical Sciences Research Council (EPSRC) in 2003 as research director and was interim CEO 2006–2007. He retired in 2008. During the years away from Strathclyde, a friendship with David and Val Sherrington was maintained and continues on with Val.

Philip Hodge

Philip gained his PhD in organic chemistry at University of Manchester in 1963. After post-doctoral posts at Oxford and Syntex (California), he joined the academic staff at the chemistry department at University of Lancaster, where he gradually rose to become a professor and head of department. He served on many EPSRC committees. In 1989, he moved to the chair of polymer chemistry in the Chemistry Department at University of Manchester. He retired in 2004. He met David Sherrington in 1977, edited two major books with him and often appeared on the same conference programmes and/or committees. They remained close friends for the rest of David’s life.

REFERENCES TO OTHER AUTHORS


**SHORT BIBLIOGRAPHY**

The following publications are those referred to directly in the text.


(2) 1980 (With P. Hodge) Polymer-supported reactions in organic synthesis. Chichester, UK: J. Wiley & Sons.


